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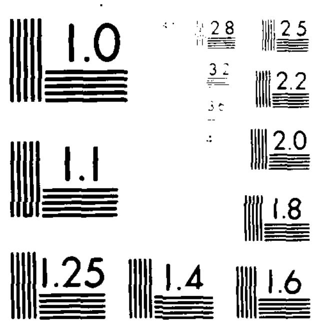

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LEVEL II

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POTENTIAL ENERGY AND CAPACITY GAINS FROM FLOOD CONTROL STORAGE REALLOCATION AT EXISTING U. S. HYDROPOWER RESERVOIRS

by

BILL S. EICHERT

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This paper describes the procedures and results of an investigation to evaluate potential increases in nationwide hydropower production that could be achieved by reallocation of flood control storage at existing hydropower reservoirs. One aspect of the investigation considered only the increase in energy that could be achieved by storage reallocation; a second aspect considered potential gains in both energy and capacity that could be achieved by adding to the existing installed capacity as well as storage reallocation. the investigation was performed by the Hydrologic Engineering (CONTINUED)

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Center of the U.S. Army Corps of Engineers, and is a component of a technical overview study which is part of the National Hydropower Study.

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POTENTIAL ENERGY AND CAPACITY GAINS FROM FLOOD CONTROL STORAGE REALLOCATION AT EXISTING U.S. HYDROPOWER RESERVOIRS[1]

by

Bill S. Eichert[2] and Vernon R. Bonner[3]

Purpose and Scope of Investigation

This paper describes the procedures and results of an investigation to evaluate potential increases in nationwide hydropower production that could be achieved by reallocation of flood control storage at existing hydropower reservoirs. One aspect of the investigation considered only the increase in energy that could be achieved by storage reallocation; a second aspect considered potential gains in both energy and capacity that could be achieved by adding to the existing installed capacity as well as storage reallocation. The investigation was performed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers, and is a component of a technical overview study (6) which is part of the National Hydropower Study (NHS) that is under the general supervision of the Corps' Institute for Water Resources.

With limited time and funds available for the investigation, a detailed evaluation of all U.S. hydropower reservoirs with flood control storage was not possible. The study procedure was based on performing detailed sequential routings with a representative sample of projects. The sample results were generalized and applied to the remaining projects to estimate the potential energy gains.

No detailed evaluation was made of the economic loss due to the reduction in flood control storage and the economic gains due to the increased hydropower energy and capacity. However, preliminary estimates on some of the projects were made during the process of the reallocation study during other parts of the technical

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[1]Paper presented at the Waterpower '81 International Conference on Hydropower, June 22-24, 1981, Washington, D.C.
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overview study of the National Hydropower Study, but they are not covered in this paper.

Data Available

The project data used for locating and analyzing candidate sites were obtained from the U.S. Army Corps of Engineers Form 2 data base which was developed for the National Hydropower Inventory Study (5). The data base was developed during a 3-year period by the Corps of Engineers District offices and includes data for over 6,000 sites. It is probably the most comprehensive data base for hydropower projects in the United States. From 67 to 689 items of information are provided for each site; however, some of the data required for evaluating hydropower potential is still farily limited. Data for the reservoirs included storages, reservoir areas, and elevations for the following: top of flood control pool, top of power pool, and bottom of power pool. Power data included existing plant capacity, a tailwater rating curve and monthly plant factors. Where monthly plant factors were not available in the NHS data base, an assumed annual plant factor of .086 was distributed in proportion to the monthly flow volumes. The flow data, for sequential routing, were average monthly flows computed from United States Geological Survey daily flow files. The flows were adjusted to the project site based on drainage area ratios. If average monthly evaporation was not provided for the site, regional evaporation data were used.

Project Input Data

The sequential routings were performed with the HEC-5 computer program "Simulation of Flood Control and Conservation Systems." (3,1) The HEC-5 input data files for each project were prepared automatically by software developed by HEC as part of the National Hydropower Study (5). Sites in the NHS data base can be selected individually based on location or the characteristics of the site. For the selected sites, the required data from the data base was automatically retrieved, checked, and converted to the proper input format. The input data files were then written on tape for subsequent analysis.

Energy and Capacity Determination

The procedures for determining firm energy were based on a series of iterative routings. Each monthly sequential routing used the historical flows during the critical drawdown period, and attempted to meet the estimated monthly firm energy schedule (safe yield concept). Each routing was made with a new firm energy estimate until the maximum reservoir drawdown during the critical period approached the preestablished bottom of power pool within an allowable error of 5 percent of the available power storage.

Each estimated monthly firm energy schedule was obtained by multiplying the monthly plant factors times the existing installed capacity times a constant. This constant is the factor that is being optimized to determine the firm energy schedule that meets the required drawdown. The length of the critical drawdown period was initially estimated by a simple empirical relationship (developed from data from over 150 sites) that estimates the critical drawdown duration as equal to 70 times the ratio of the power storage to mean annual flow. Thus, a 1.0 power storage to mean annual flow ratio would indicate an estimated drawdown duration of 70 months. The initial critical period was then determined by finding the historical period of flow that had the minimum flow volume for the duration corresponding to the estimated critical drawdown period. The firm energy was determined by the iterative routing procedure described above for the assumed critical drawdown period. The derived firm energy schedule for the assumed critical period was tested against the entire period of flow record by making another sequential routing. If a more severe critical period was found, the process was repeated for the new critical period. When the derived firm energy schedule produced the most severe power drawdown in the period of reocrd, the firm energy and the average annual energy (AAE) based on routing the entire period of flow record were adopted for the site. Where the existing installed capacity was not allowed to increase, the optimal constant was multiplied by the input monthly plant factors to obtain the new monthly plant factors corresponding to the derived firm energy. Where the installed capacity was allowed to increase, the optimized constant was multiplied by the existing installed capacity to obtain the proposed installed capacity. The dependable capacity was assumed to be equal to the proposed installed capacity since it was the minimum capacity that could be provided during the critical drawdown period (within the allowable drawdown error).

Optimization Features

The above procedures for determining the firm energy and installed capacity from a given amount of power storage for a single reservoir are performed automatically by the HEC-5 program (3) as shown on Exhibit 1. Options available in HEC-5 allow the user to optimize firm energy only (without changing the installed capacity) or to optimize firm energy and installed capacity based on a given amount of power storage. These two procedures were both used in the reallocation studies reported in this paper. Other program options (see Exhibit 2) include optimizing reservoir yields for water supply requirements or diversions, or for optimizing reservoir storage based on fixed water supply yields, diversions or energy requirements.

Project Selection

To locate the most likely projects for reallocation of flood control storage, the data file of the NHS was searched to identify all projects with power plants and flood control storage. A total of 187 projects were found that met the criteria (see Exhibit 3);

however, many of the projects had very little flood control storage. Considering the study objectives, a second search of the NHS file was made with the added constraint that the flood control storage must be at least equivalent to 10 percent of the mean annual flow. Only 49 of the projects met the added criterion.

Sequential Routing Studies

Because only 49 projects were judged to have sufficient flood control storage to warrant detailed study, an attempt was made to analyze each site. HEC-5 input data files were initially generated and stored for a total of 34 projects. The remaining 15 projects had data errors or deficiencies that prevented the automatic generation of an HEC-5 input file. Subsequently, five of the remaining 15 sites were included in the study by making small corrections to the NHS data file.

With input data files for 39 of the 49 large storage sites, detailed sequential analysis of each project was performed. The automatic search procedure, previously discussed, was used to determine the maximum firm energy using the safe yield concept. The maximum firm energy was obtained when the power storage utilization was within 5 percent of the total power storage available. With the derived firm energy, the complete sequential analysis for the period of recorded flow data was performed to ensure that the derived firm energy can be produced and to provide an estimate of the average annual energy (AAE) for the project.

Energy for Base Conditions

The procedures for deriving firm energy and the resulting AAE were performed for the existing power storage for the 39 projects as a basis of comparison for the reallocation study. The AAE values, entered on the NHS data files by the Corps Districts as representing existing conditions, were compared to the HEC-5 estimates. The total for all the projects analyzed was about 12 percent below the total from the NHS data file. Approximately 40 percent of the projects checked within 10 percent. A number of reasons to explain the differences are presented later in the paper. The energy computed by the HEC-5 program based on data from the NHS data base, nevertheless, was judged to be sufficiently accurate to use as the base condition for estimating the potential gain from reallocation.

Energy Increases from Storage Reallocation

The estimates of potential gain in energy from reallocating storage were made by reallocating first 10 percent and then 20 percent of each project's flood control storage to the power pool. With the power pool increased by the flood storage reduction, and without allowing an increase in installed capacity, the firm and AAE were again computed for each project. Because the installed capacity was not allowed to increase, the additional storage

resulted in higher plant factors and more firm annual energy. The gains in AAE and firm annual energy for each were then related to the existing condition estimate of energy production to compute the percent gain in energy.

The estimated AAE for the 39 projects under existing conditions was 14,167 GWH. With an increase in power storage from reallocating 10 percent of the flood control storage, the AAE increased 257 GWH to a total of 14,424 GWH (a 1.8 percent increase in AAE). By reallocating 20 percent of the flood control storage, the AAE increased 483 GWH above existing to a total of 14,650 GWH (a 3.4 increase in energy). A few projects were analyzed with even higher percentages of flood control storage reallocated, although it is doubtful that it would be economically and socially possible to reallocate that much storage. In general, the rate of increase in AAE decreased slightly with increased reallocation of storage; however, the response was nearly linear. One of these 39 projects was later dropped from the technical overview study (6) because it was a pumped storage project.

Larger (but unrealistic) increases in AAE could have been obtained by operating the projects at the top-of-power pool with no firm energy requirements. However increased spills would offset most of the gain due to increased head. For the 5 reservoir White River System in Arkansas, for instance, an additional 3 percent gain in AAE can be obtained by this method based on monthly routings.

Another result of the HEC-5 analysis was the determination of the increase in firm energy and plant factor for the projects with each allocation of power storage. By adding to the power storage, the projects are able to meet higher power demands during critical low-flow periods and to operate more hours per day on the load. The increase in firm annual energy was approximately three times the increase of the AAE. The total increase for the 10 percent and 20 percent reallocation is shown below:

Table 1. Changes in AAE for Storage Reallocation

% Reallocation of Flood Control Storage	% Increase in Power Storage	% Increase Average Annual Energy	% Increase Firm Annual Energy
10	5.5	1.8	5.3
20	11.1	3.4	9.8

Capacity and Energy Increases from Storage Reallocation

To evaluate the potential for increased installed capacity at existing sites, detailed sequential analyses were performed for each of the previously described sites to determine their dependable capacity at varying plant factors. Annual plant factors of 5 percent,

10 percent and 25 percent were selected as representing the range of operation for most hydropower plants. It was assumed that no new plant would be installed at greater than dependable capacity and that a 5 percent plant factor was a lower limit on plant operation; and, therefore, the maximum probable capacity. The HEC-5 sequential analysis was used as before, except for this analysis, the input energy demand schedule was adjusted so that the average plant factor was equal to one of the three plant factors: 5 percent, 10 percent or 25 percent in each of three runs. The program determined the dependable capacity, firm energy, and AAE using the automatic search procedure previously described. Computer simulations for all three plant factors were made for both existing storage allocation and for the reallocation of 10 percent of the flood control storage.

When the installed capacity was allowed to increase based on the existing power storage, a total of 56 percent of the projects showed some increase in average annual energy for one of the three assumed plant factors as compared to the base condition. Of those projects with a gain, the total gain amounted to a modest 3.6 percent. When the AAE for all 39 projects was compared to the base condition, the gain only amounts to 2.3 percent. One of the primary reasons all of the projects did not show a gain in AAE was that 15 percent of the projects apparently were installed at less than a 5 percent plant factor. Another reason for a few of the projects not showing a gain in AAE is that when the plant factor was decreased in order to increase the dependable capacity, a larger discharge was required to meet the new capacity, which resulted in a higher tailwater elevation. In some cases, the decrease in power head caused by the tailwater overcompensated for the reduced spill quantity due to the higher installed capacity.

The primary gain in AAE for existing power storage comes from increased utilization of water which cannot be passed through the generators (spills). The simulation uses all water released, up to the maximum generation capability of the plant, in calculating the AAE. With the increased plant capacity, the magnitude and number of spills decrease. To determine the upper limit of the energy generation, the projects were operated with existing plant factors and power storage, but with unlimited capacity to generate dump energy. The resulting gain in average annual energy was 5 percent. That is, with unlimited installed capacity at all 39 projects, a maximum gain of 5 percent in average annual energy would result. As previously stated, if the installed capacity was established based on a minimum 5 percent annual plant factor, then only a 2.3 percent increase in AAE would be realized in the 39 projects.

Approximately the same number of projects showed a gain in average annual energy when 10 percent of the flood control storage was reallocated and the installed capacity was increased. The same three annual plant factors were used to determine the dependable capacity and firm energy with the increased storage. The gain in average annual energy amounted to 5.5 percent for those projects

showing a gain. When compared to all projects analyzed, the gain is approximately 3.4 percent which is a little over twice the 1.6 percent gain due to storage change alone. Again, the previous explanations account for why some projects did not shown an appreciable gain in energy production.

Table 2. Changes in AAE for Storage Reallocation and Increased Capacity

% Reallocation of Flood Control Storage	% Increase in Power Storage	% Increase Avg. Annual Energy (projects with gain)	% Increase Avg. Annual Energy (all 39 projects)
0	0	3.6	2.3
10	5.5	5.5	3.4

While almost half the projects did not have a gain in AAE from increasing the installed capacity for reasons explained above, the expected gain from increasing capacity is primarily to add dependable capacity to the power system, and not to increase average annual energy. Since 85 percent of the projects had plant factors greater than the assumed practical limit of 5 percent, all of these projects could have their dependable capacity increased and still operate at or above the 5 percent plant factor. Approximately 40 percent of the projects appeared to be operating in the 5 percent to 15 percent range of plant factors based on the simulation results.

The change in installed capacity has an inverse relationship with the plant factor. For example, the capacity would have to double if the plant factor changes from 10 percent to 5 percent and the same amount of firm energy was produced. When the plant operates at full installed capacity, the reservoir release necessary to generate that capacity would also double. Therefore, an important constraint to increasing installed capacity for peaking operation is the higher discharges necessary to produce the higher capacity.

The increase in firm energy (and dependable capacity) was about three times the increase in AAE as it was for the previous storage allocation study. The derived dependable capacity of the projects increased 188 percent when the existing composite plant factor of all projects of 18 percent was decreased to 5 percent, without changing the storage allocation. By also increasing the power storage by 5.5 percent, the dependable capacity increased 196 percent.

Generalizing Results by Regression

The results from regression analysis using the computer program, "Multiple Linear Regression" (4) indicated a linear model provided the best fit over the range of data analyzed. In a few instances,

the reallocation of 10 and 20 percent flood control storage provided a very large increase in power storage. Because the regression equation was to be used on projects with flood control storage less than 10 percent of the annual mean flow, these large increases in power storage were not used in the final regression analysis. Using a total of 71 samples (from the 10 percent and 20 percent flood control reallocation), regression equations were derived for the percentage increase in AAE.

Regression analysis with percentage increase in firm annual energy as the dependent variable were less successful than with AAE. The standard error for the firm energy estimate was much larger than that for the AAE because the variability of firm energy is much greater. The large unexplained variability in the prediction of firm energy stems largely from the variability of the demand, the supply of water, and the degree the two are in or out of phase. There was no convenient way to bring those aspects into the regression analysis for this study. Use of the regression equation to the remaining projects of the 187 sites gave a total gain in AAE for all sites of 652 GWH for the 10 percent allocation and 1,225 GWH for the 20 percent allocation of flood control storage. This appears to be small; however, the energy increase made possible by the 10 percent reallocation would require the equivalent of about 1.3 million barrels of fuel oil annually.

Limitations of Study

With most of the large storage projects included in the detailed sequential analysis (representing approximately 40 percent of the energy gain), the estimates of energy gain should be fairly accurate. The procedure used depends primarily on the accuracy and adequacy of the NHS data files, which cannot readily be evaluated. One key item missing on most of the projects was the nondamaging channel capacity below the dam. This data limitation caused too much spill to be calculated for those projects that might be in flood control operation for several months at a time due to the limited channel capacity. Thus, the total energy gains calculated due to reallocation (modest as they were) were perhaps somewhat higher than they should be due to the data inadequacy for the existing storages of the 5 Reservoir White River System, where the channel capacity data would be expected to be important, the AAE was about 1 percent too low due to the missing channel capacity.

Principal assumptions in the study procedure center on the application of the safe yield concept used to determine firm energy based on the specified plant factors in the NHS file. The actual sequential analysis was based on monthly flow data and single project operation for hydropower exclusively. Average annual energy for some projects (especially smaller storage projects) can be overestimated using monthly flows because the spill should be evaluated on at least a daily basis. Other project purposes generally curtail power production and therefore the simulation results might be

expected to be on the high side for that reason. However, because the total energy estimate from the simulation was lower than the NHS file total, the single purpose analysis does not appear to overestimate the AAE.

Several operational procedures, not considered in the simulation, probably account for the simulation results being generally lower. For example, flood control operation could, in some cases, give higher energy values than estimated. For projects that remain in the flood control pool for long periods, the added head and decreased spill would provide more energy. If this were the case, the estimated base energy for existing storage allocation would be too low and the expected gain from reallocation would be too high. Also, any existing seasonally varying storage allocation would provide more power storage as the flood season passes. The possible existing seasonally added storage would provide a portion of the expected gain from reallocation of storage.

Some of the projects may also have unique diversions for power supply or pump-back operation that would provide more energy than was estimated. Multiple reservoir operation may also provide system flexibility which would also increase the present energy production over that estimated by single site simulation. A comparison was made on the White River System to evaluate the results from the single site simulation.

The Southwestern Division (SWD) of the Corps of Engineers provided an independent analysis of the potential gain from the reallocation of storage in projects in the White River System. Using a different computer model (7) that simulates their operation plan and the entire system with daily flow data, SWD provided AAE values for the existing storage allocation and for several reallocations of flood control storage. When the total AAE computed by the two programs was compared for the five storage projects, the monthly individual project operations using the HEC-5 results were about 11 percent below those from the SWD, which is close to the 12 percent difference with the NHS user-supplied estimates for the 39 projects. Subsequent discussions with SWD located some of the differences. The largest difference is probably due to data differences, especially flows. The estimated differences in operation amounted to about 2-3 percent differences in AAE.

When the SWD projects are in flood operation, the water stored in the flood pool is generally released at rates which do not exceed the power generating capability, and that method of operation is reflected in their simulation. With the HEC-5 single project analysis, monthly flows in excess of power storage are dumped during the month they occur which is the method of operation traditionally used for flood control projects before dump energy values skyrocketed. The HEC-5 monthly operation will show less energy generation because the program spills any water which would

be stored in the flood pool and cannot be diverted through the penstock. Furthermore, because the channel capacity was assumed as unlimited, the maximum head that can be reached is the top-of-power pool. For every day the White River System is in flood control storage, the projects are operating at a higher head and, therefore, have a greater energy potential.

As expected, the SWD simulation also shows less gain in energy from reallocating flood control storage to power storage. By their current operation, SWD is already gaining most of the added energy by minimizing any spill even when they are in the flood control pool. By their estimation, reallocating 30 percent of the flood control storage to power would only provide an additional 0.5 percent in AAE. The sum of the HEC-5 results for the five projects shows a potential 4.3 percent gain from reallocating 20 percent of the flood control storage.

Flood Damage Evaluation

The reallocation study did not explicitly estimate the cost (increase in annual damages) associated with reallocating storage from existing flood control space to power storage space. It was not possible to perform the analysis on a national scale because of the dependence of increased damage on the specific flood control operations of each project and the relationship of the site to downstream damage for which data were not available. In addition, the flood hydrology would have to include the resulting response in flood control system operations for which data also were not available on a national scale. The reallocation issue is a sensitive and potentially controversial one so that it was also difficult to make use of case study approaches to perform the estimate. On the positive side, however, it is apparent that the three case studies that were performed are reasonably representative in that there is probably a relatively small increase in annual damages for the first increments of loss in flood control storage. Nonetheless, allocating storage space from flood control to power without compensation measures to provide essentially the same flood control performance is unlikely. The lack of a specific assessment of the increased damage due to reallocation does not materially affect the results of the investigation because storage allocation in existing power projects does not appear to be a major contribution nationally to increasing the average annual energy.

Conclusions

Reallocation of flood control storage, for any purpose, is a sensitive issue. Of course, flood plain residents will be concerned that their flood protection might be reduced by even minor amounts. This fear alone might be sufficient to stop implementation of a new reallocation plan regardless of its benefits. This study has shown that, from a national standpoint, embarking on a large program of

reallocation for existing hydropower projects would not result in a major increase in average annual energy. However, this should not deter periodic reviews of existing plant design and storage allocations using updated information based on actual plant operations. It is possible that project design conditions have changed such that a portion of the originally required flood control storage can be reallocated to power storage with negligible effects on flood damage below the dam and on other project purposes. On the other hand, the possibility also exists that the original flood control storage at some of the older sites might be inadequate based on current storage sizing standards.

There is a small gain in average annual energy (AAE) from reallocating significant portions of flood control storage to power storage. The indicated gains in average annual energy from the case study operations are significantly smaller than those estimated from techniques used in this paper. The primary reason for the smaller gains is the method of operating the projects. Some projects are operated to minimize power spills even while in the flood control pool. By minimizing spills and operating for hydropower within the flood control pool, the majority of the potential gains in AAE from reallocating storage can be achieved. However, gains in annual firm energy are approximately three times the gains in AAE and they are not currently being obtained by more power-oriented rules. The major contribution of reallocation is in firming up the output, i.e., converting energy that would presently be characterized as "secondary energy" to "firm energy." In some instances they may be of substantial value.

It therefore appears that each existing power project should be evaluated for potential power gains and to see the effects on flood control operation if more power-oriented rules are developed to minimize spills. By limiting flood control release rates to the discharge corresponding to the maximum power generation, it seems that most of the potential gain in AAE from reallocating storage can be realized. The ability to consider power requirements within the flood control pool would depend on the amount of flood control storage, the ability to forecast future flood inflows and the ability to evacuate the flood control space in a flood emergency. The nature of the problem would require a project-by-project analysis.

In summary, the data and evaluation methods used in this study are believed to provide reliable identification of the major factors influencing potential increases in energy output at existing sites and to yield sufficiently accurate estimates of achievable energy increase. Conclusions for any specific site would require more detailed site specific data and assessments.

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EXHIBIT 1

EXAMPLE OF ENERGY AND CAPACITY OPTIMIZATION[1]

Flow Data Set Number	Iteration Number	Number of Periods of Rout	Drawdown Storage Error Ratio	Assumed Firm Energy (Oct)	Corres-ponding Capacity	Ave Q	Ave H	Draw Periods	Line
1	1	31	+.38	587.93*	9189	87.82	122.88	42-51	1
	2	31	-.16	622.66	9731	94.11	105.12	34-56	2
	3	31	-.05 *	600.01*	9378	94.05	114.05	34-56	3
2	1	168	-.33	600.01	9378	91.44	92.15	33-82	4
3	1	58	-.33	600.01	9378	91.44	92.15	33-82	5
	2	58	+.97	449.88	7031	56.17	130.45	45-47	6
	3	58	+.84	505.80	7905	64.45	128.12	45-50	7
	4	58	+.69	539.56	8433	74.51	126.46	43-50	8
	5	58	+.58	559.93*	8751	78.47	124.71	43-50	9
	6	58	-.02	585.41*	9149	93.64	114.17	41-82	10
4	1	168	-.02	585.41	9149	93.64	114.17	41-82	11

Description

Project: NC6SAC0061, Mitchell River Reservoir
USGS Gage 2112350, Period of Record - 168 months
Power Storage = 17,500, Mean Q = 123 cfs
Head: Top of Power = 131, Bottom of Power = 121.8

*Assumptions resulting in both negative and positive drawdown errors are with 5 percent of each other.

[1]For each flow data set, a series of monthly sequential routings are performed, with different assumed firm energy and corresponding capacity, until the drawdown storage error ratio is less than .05. The first flow data set is for the initial estimate of the critical drawdown period; the second and fourth are for the full period of flow record to see if the previous critical period was the most severe; the third flow data set is for the new critical period determined from flow data set 2.

EXHIBIT 2

HEC-5 OPTIMIZATION CAPABILITIES

1. Number of independent reservoirs to be optimized at one time (1 to 5).

2. Parameters that can currently be optimized:

   a. At-site conservation storage

   b. At-site monthly power requirements and installed capacity

   c. At-site monthly power requirements without changing installed capacity

   d. At-site minimum desired flow

   e. At-site minimum required flow

   f. At-site diversion schedule

3. Initial Estimates of Parameter to be Optimized

   a. Monthly power requirements - by user input or by default based on approximate equation using flows and head available during critical period.

   b. All others - currently only by user input.

4. Flow Data - Monthly

   a. Input critical period data only, or

   b. Input period of record data

      (1) User can specify starting and ending period of critical period

      (2) User can specify length of critical drawdown (computer will then select period with minimum volume for that duration)

      (3) User can allow computer to select critical drawdown period based on equation that drawdown length = 70 * ratio of power storage to mean annual flow.

5. Optimization Use of Flow Data

   a. Optimization can be made for all flow data furnished (each routing made for an assumed firm energy will use all flow data furnished).

   b. Optimization can be made for initial estimate of critical period, then a single period of record routing will be made (called 1 cycle).

   c. Same as first cycle described in b, plus an additional optimization will be made on the new critical period found (if one is found from the period of record routing) and then a new single period of record routing will be made (called 2 cycles).

   d. Same as "c" except 3 cycles.

   e. Same as "c" except 4 cycles.

6. Allowable Error in Drawdown

   a. Negative error (drawdown is too great) in acre-feet or 1000's cu meters

   b. Positive error (not enough drawdown) as percentage of conservation storage.

   c. Negative and Positive Errors are same as percent of conservation storage.

EXHIBIT 3

OWNERSHIP AND PLANT TYPES OF POWER PROJECTS WITH
FLOOD CONTROL STORAGE

Owner Category	Number of Projects	Plant Type	Number of Projects
1. Corps	50	1. Run of River	22
2. Other Federal	14	2. Diversion	7
3. Non-Federal, Government	27	3. Reservoir	149
4. Investor-Owned Utility	27	4. Reservoir with Diversion	8
5. Cooperatively-Owned Utility	11	5. Other	1
6. Other Commercial or Industrial Firm	50		
7. Private Citizen or Non-Utility Cooperative	5		
8. Unknown	3		
Total	187		187

TECHNICAL PAPERS

Technical papers are written by the staff of the HEC, sometimes in collaboration with persons from other organizations, for presentation at various conferences, meetings, seminars and other professional gatherings.

Price

- \# 1 Use of Interrelated Records to Simulate Streamflow, Leo R. Beard, December 1964, 18 pages.
- \# 2 Optimization Techniques for Hydrologic Engineering, Leo R. Beard, April 1966, 22 pages.
- \# 3 Methods of Determination of Safe Yield and Compensation Water from Storage Reservoirs, Leo R. Beard, August 1965, 17 pages.
- \# 4 Functional Evaluation of a Water Resources System, Leo R. Beard, January 1967, 28 pages.
- \# 5 Streamflow Synthesis for Ungaged Rivers, Leo R. Beard, October 1967, 23 pages.
- \# 6 Simulation of Daily Streamflow, Leo R. Beard, April 1968, 15 pages.
- \# 7 Pilot Study for Storage Requirements for Low Flow Augmentation, A. J. Fredrich, April 1968, 26 pages.
- \# 8 Worth of Streamflow Data for Project Design - A Pilot Study, D. R. Dawdy, H. E. Kubik, L. R. Beard, and E. R. Close, April 1968, 17 pages.
- \# 9 Economic Evaluation of Reservoir System Accomplishments, Leo R. Beard, May 1968, 20 pages.
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